Instrumental AAOI reconstructions and comparison with the HadSLP1/2 AAOIs and pattern nudging for assimilation of instrumental/proxy data

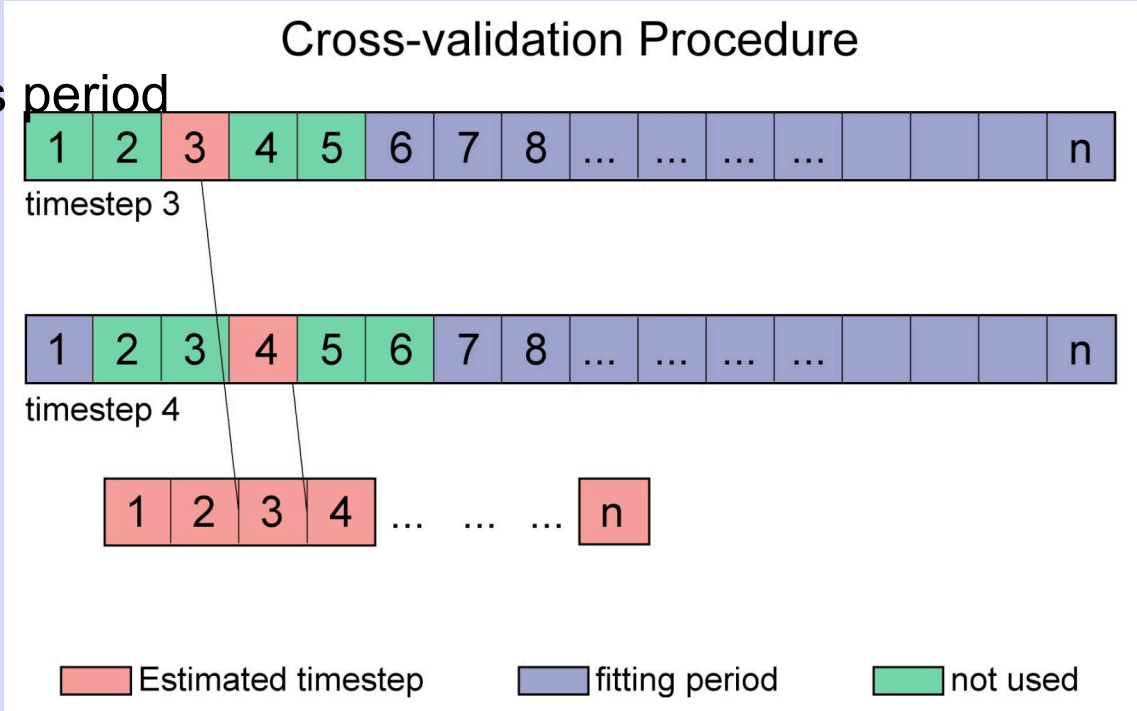
Julie Jones and Martin Widmann
Institute for Coastal Research
GKSS Research Centre
Geesthacht
Germany

Rob Allan, Tara Ansell
Hadley Centre, Exeter

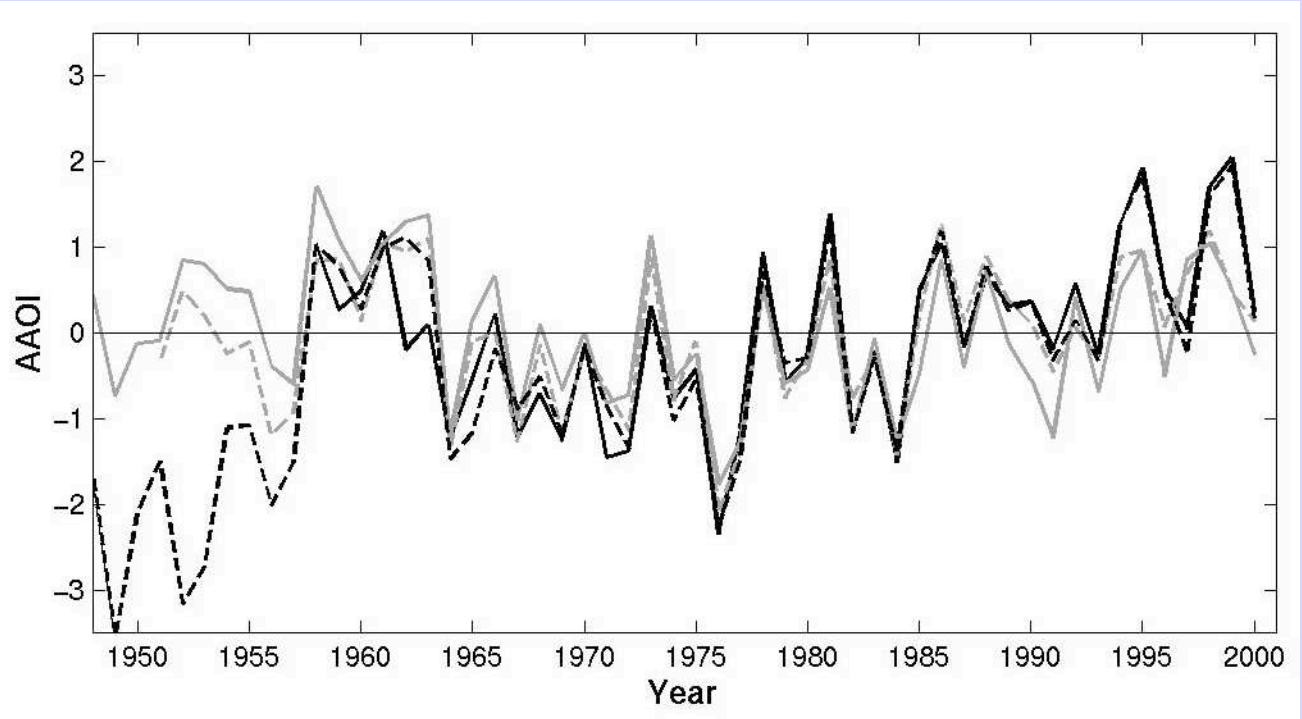
jones@gkss.de widmann@gkss.de

Method for station-based AAOI reconstruction

- station SLP data obtained from Phil Jones (and later from Rob Allan/Tara Ansell
- stations selected that are significantly correlated with detrended ERA40 AAOI at the 5% level
- Regression between the detrended ERA40 AAOI and PCs of detrended station data (principal components regression, PCR).
- A cross-validation method (shown below) was used because of the short reanalysis period



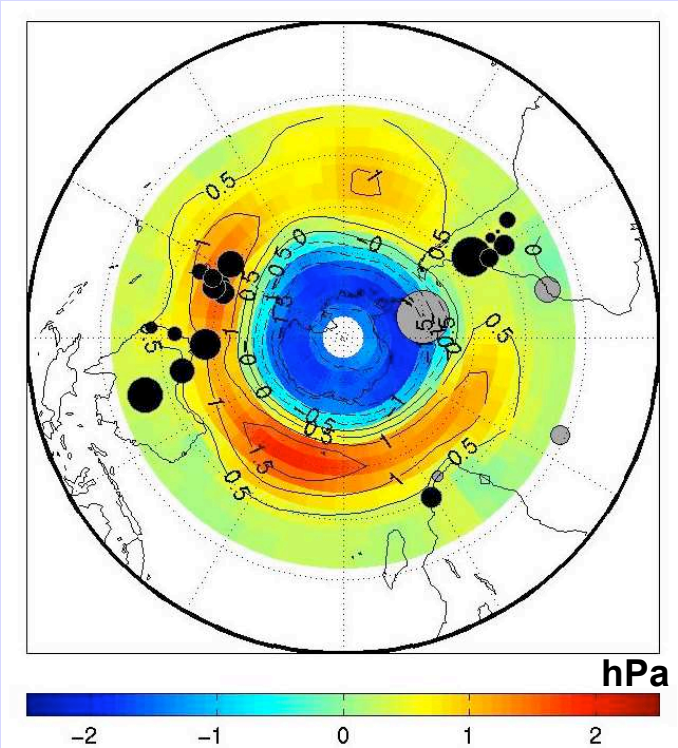
Strong AAOI trend, particularly in DJ



Modelling and observational studies link this trend to stratospheric ozone depletion* and to greenhouse gas induced climate change

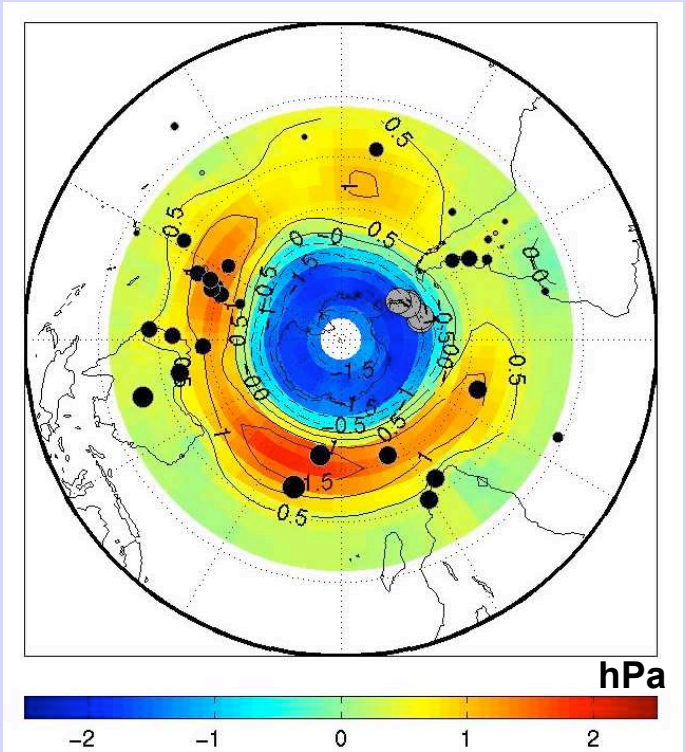
*Thompson and Solomon, Science 2002, Gillett and Thompson,Science, 2003

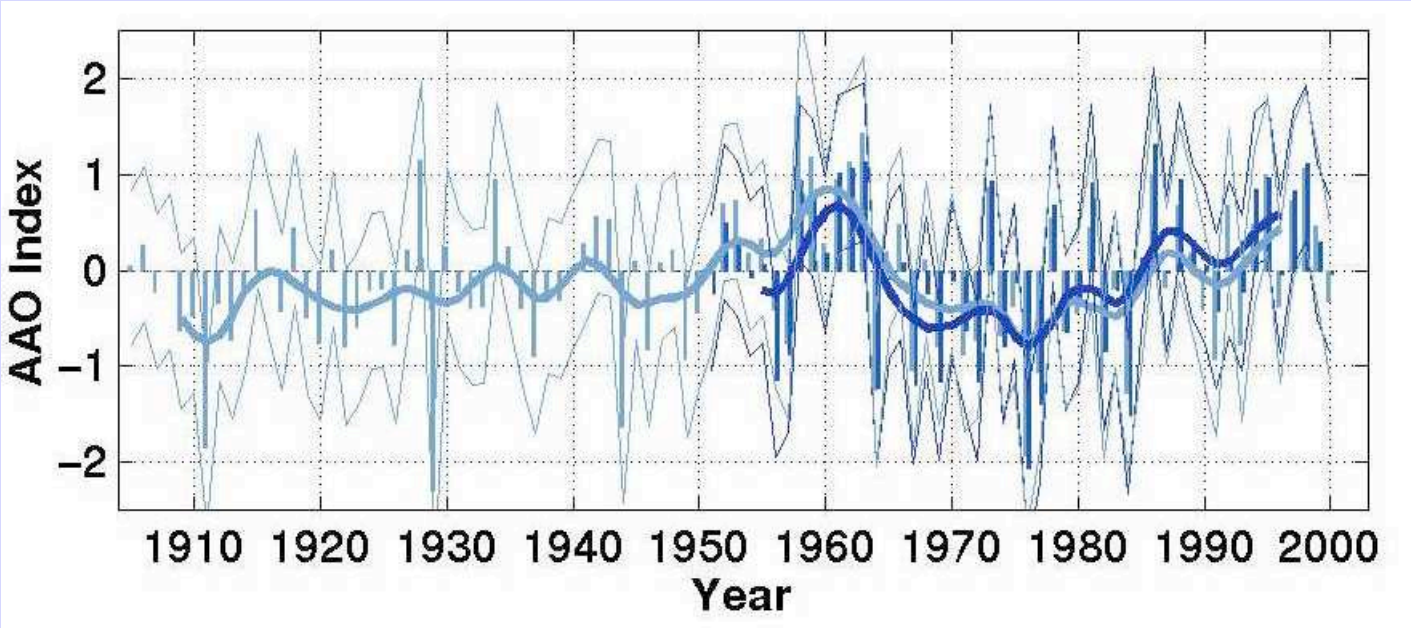
DJ AAO reconstructions



1905 reconstruction:
22 stations
r_{val} = **0.88**
RE = **0.77**

1951 reconstruction: 41 stations
r_{val} = **0.90**
RE = **0.81**



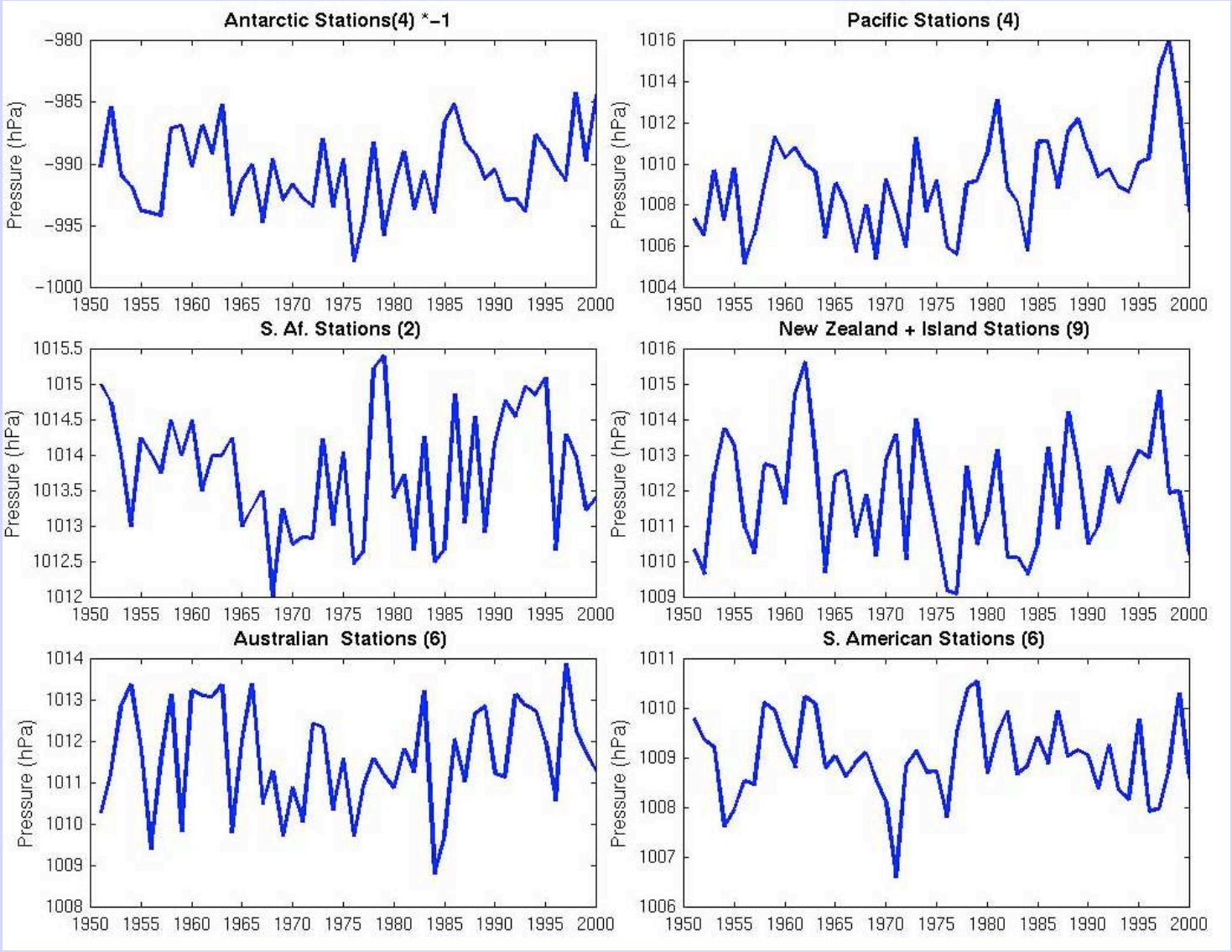


- Values in the 1960s at least as high as at present, and strong negative trend after this
- The DJ AAOI shows strong trends between 1940s and 1960s - before ozone depleting chemicals emitted

thus other mechanisms to stratospheric O_3 depletion or greenhouse gases can result in changes of similar magnitude to those seen over the last decades - external forcings or internal climate variability?

Jones, J. M and Widmann, M., *Nature*, 432, 290-291

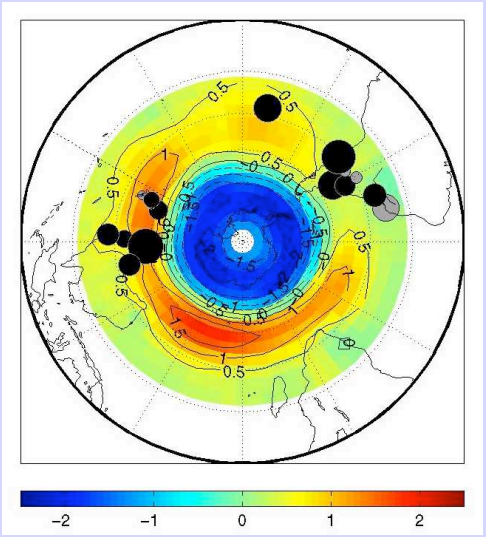
(Inverse) DJ station pressure



- The ‘60’s bump’ is evident in the station data

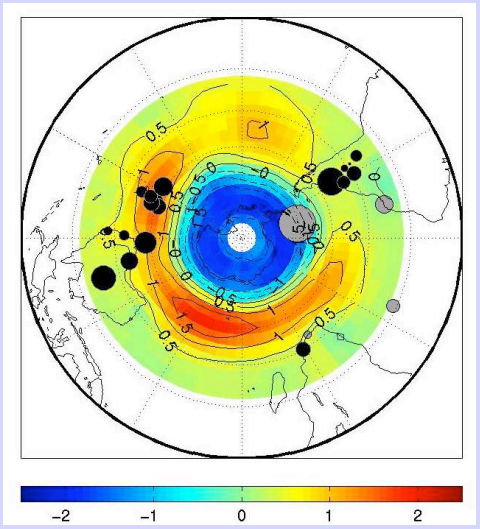
How does the DJ AAOI look further back?

Reconstruction back to 1866 using additional station series provided by Rob Allan and Tara Ansell



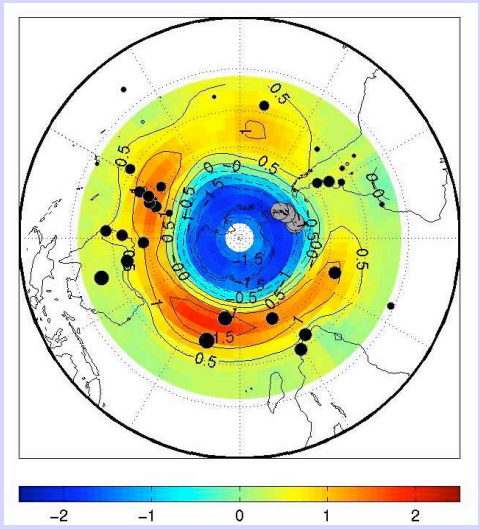
hPa

1866: 16 stations
r = 0.83, RE = 0.68

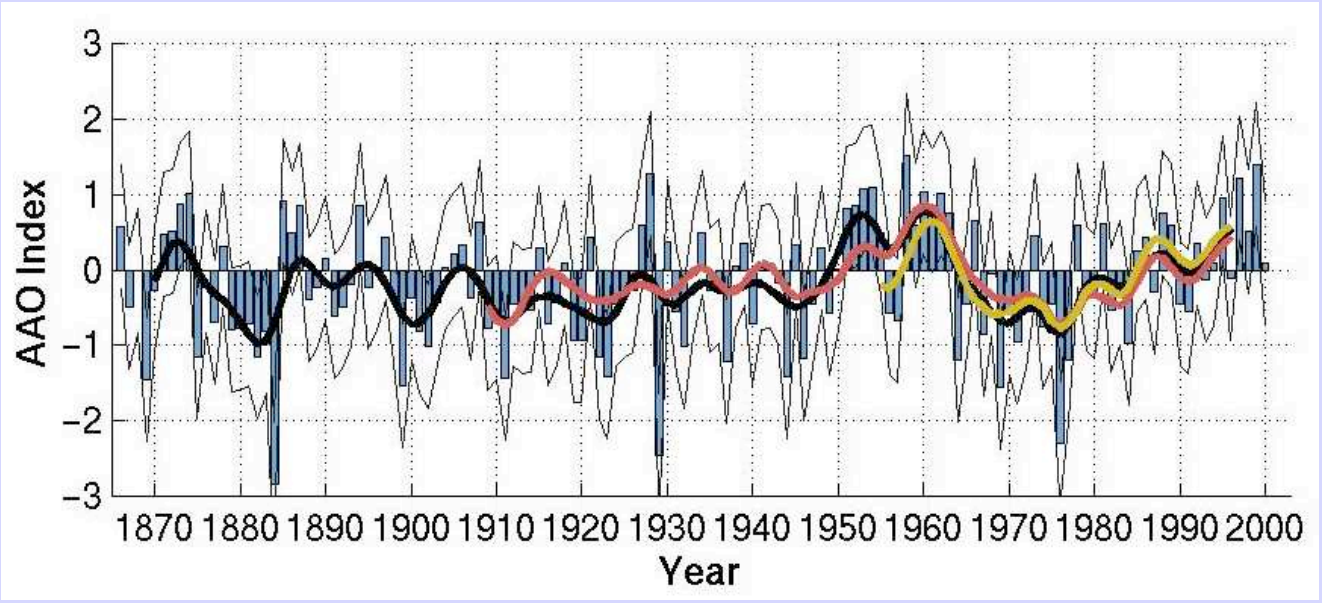


hPa

1905: 22 stations
r = 0.88, RE = 0.77



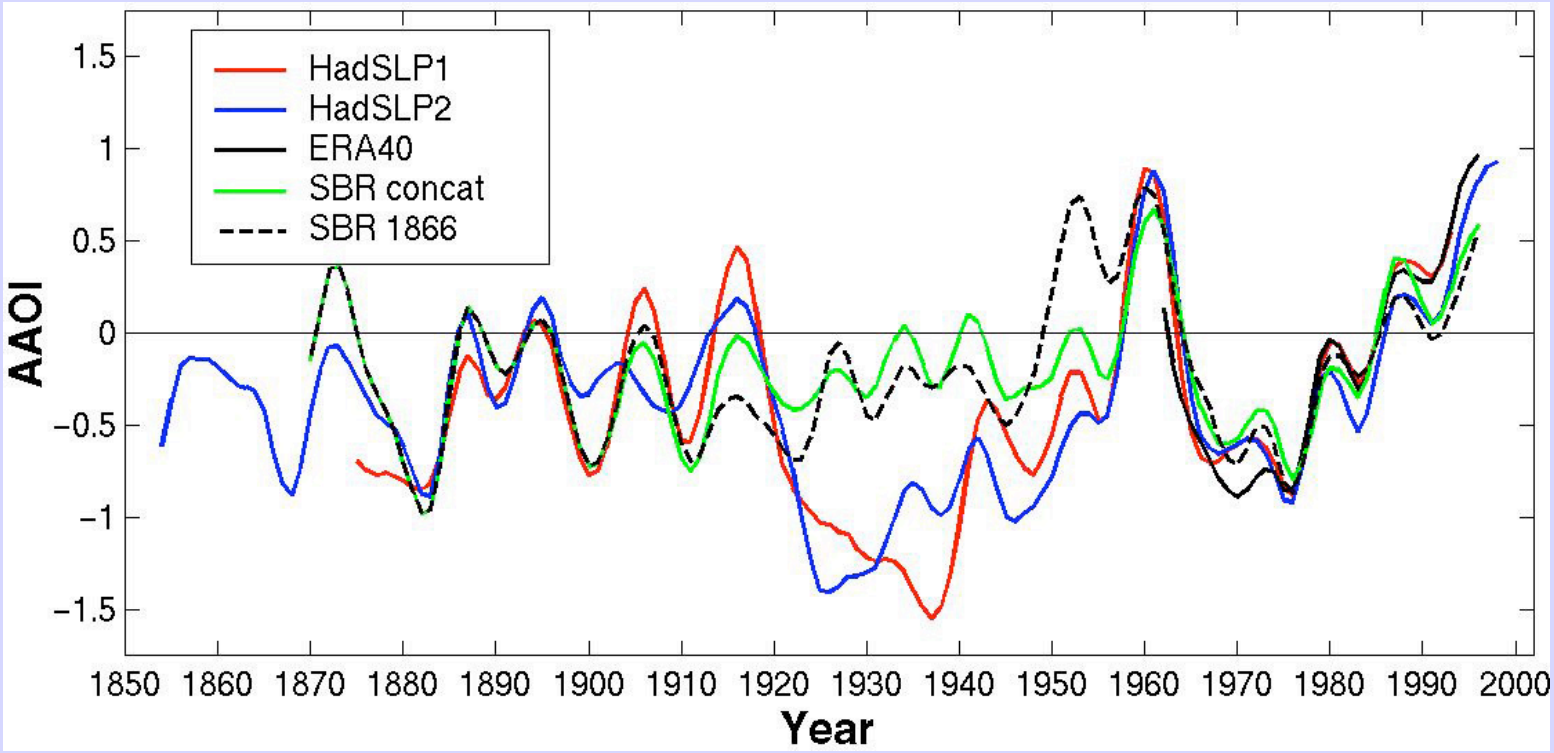
1951: 41 stations
r = 0.90, RE = 0.81



	Interann	9-yr
$r_{1866/1905}$	**0.86**	**0.91**
$r_{1866/1951}$	**0.84**	**0.91**

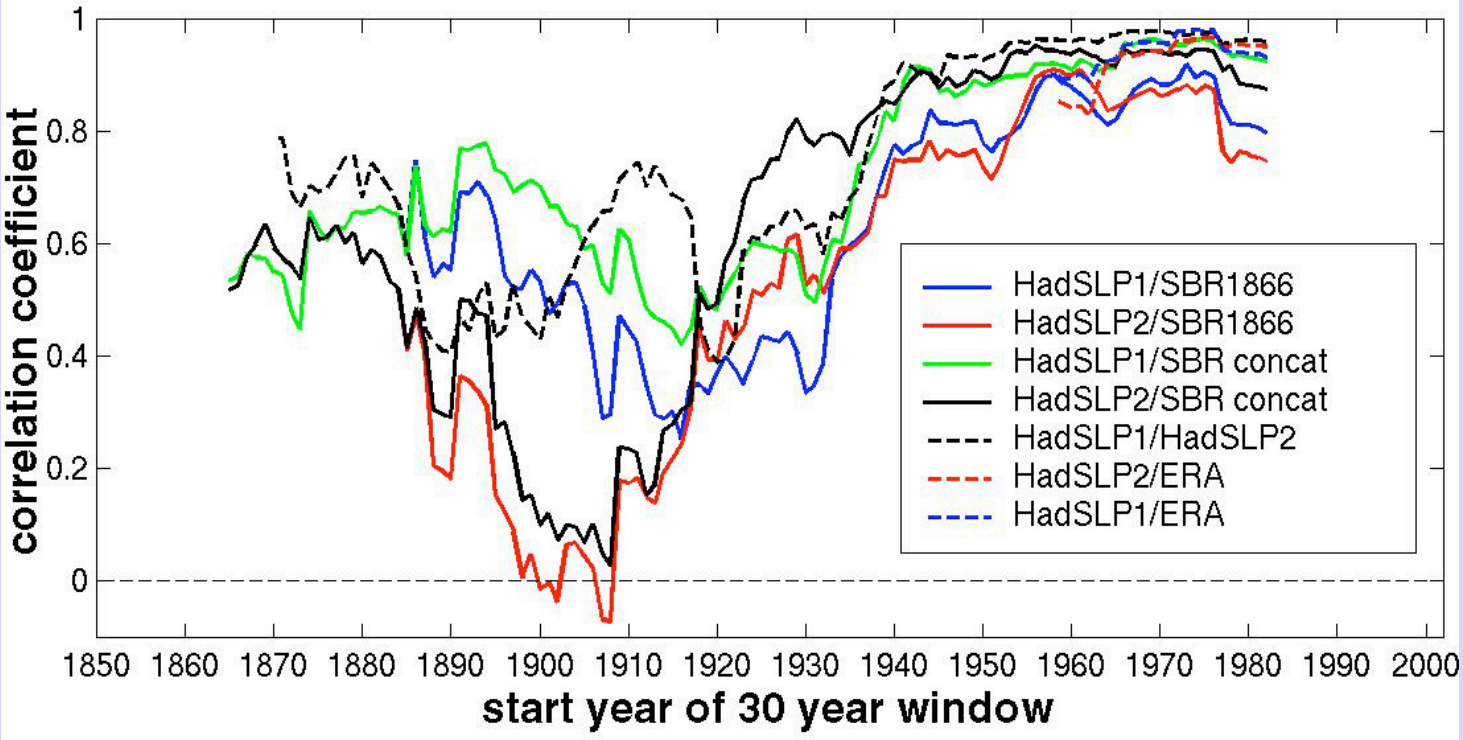
1866
1905
1951

Comparison of the DJ AAOI reconstruction with the HadSLP AAOIs



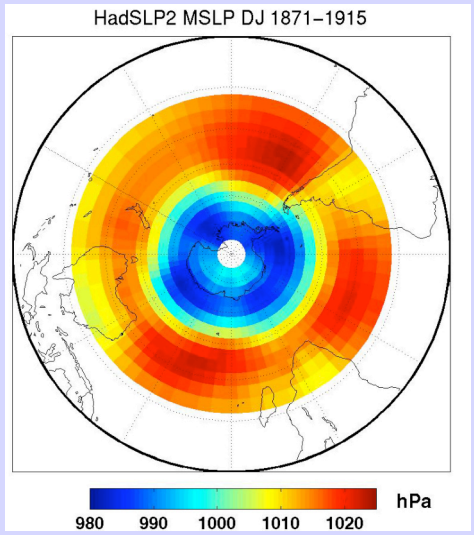
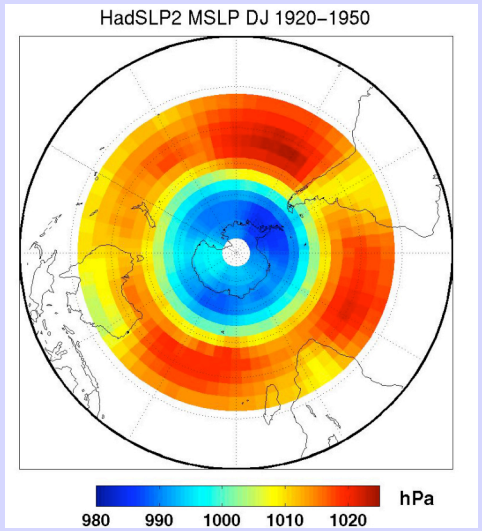
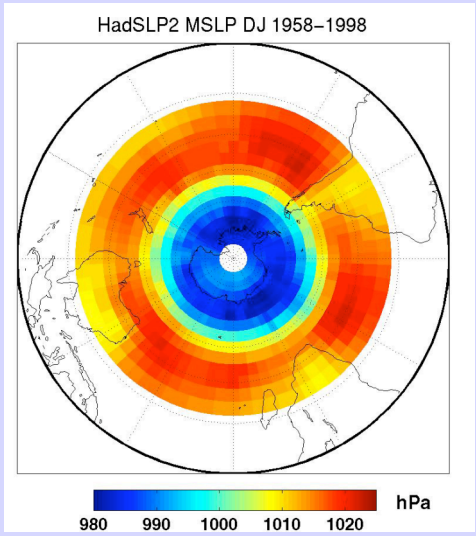
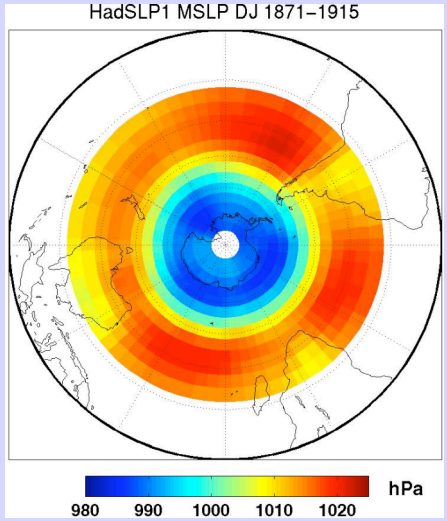
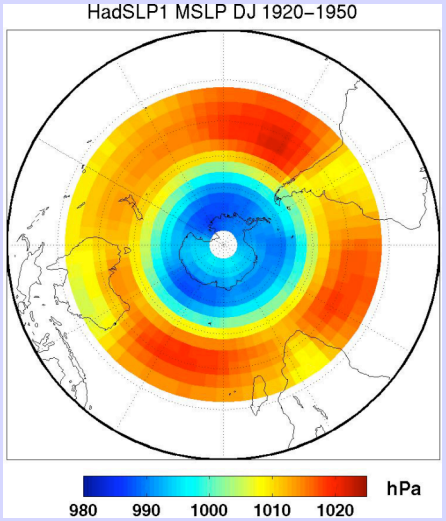
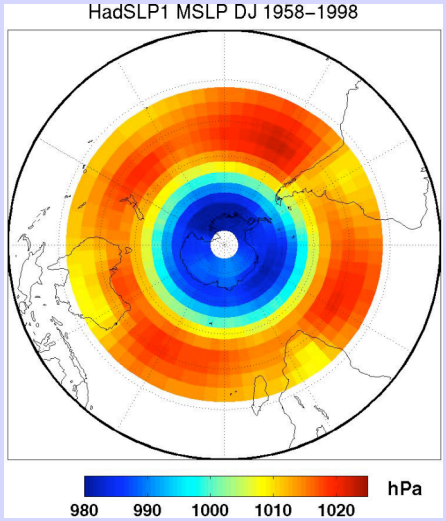
- agreement during reanalysis period good (r=0.92/0.89)
- agreement during early period reasonable – better with HadSLP1 than with HadSLP2
- strong disagreement between SBR and HadSLP in 1920-1950 period
- 60‘s bump present in HadSLP1/2

Correlations between DJ AAOIs for a 20 year running window



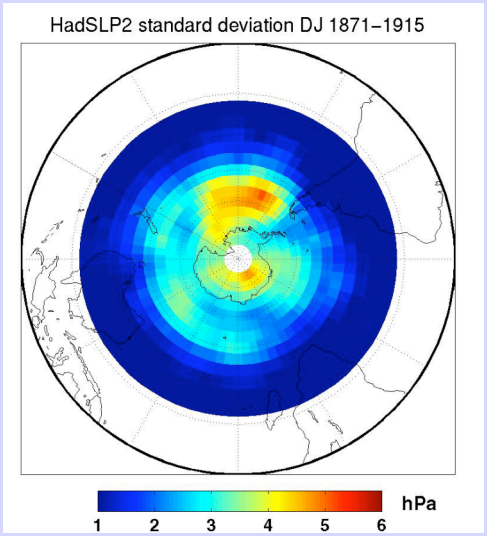
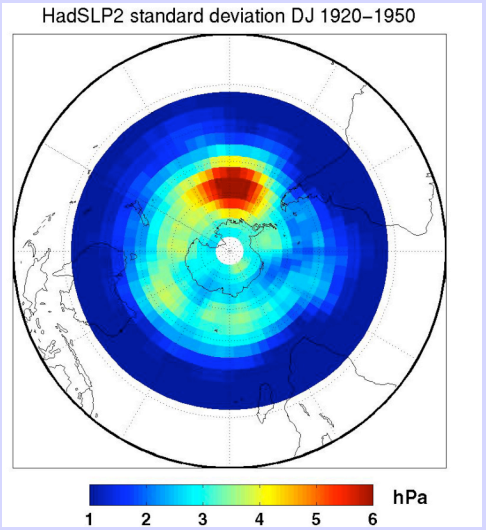
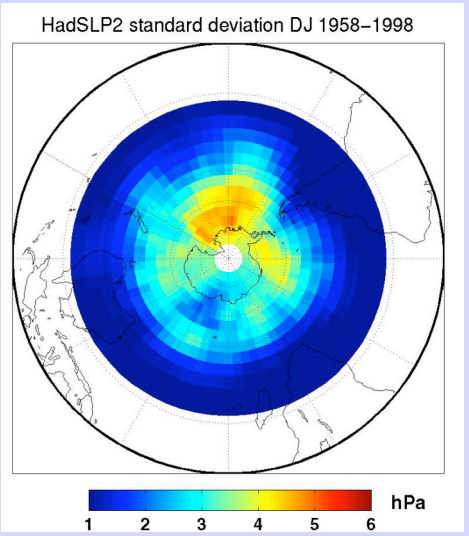
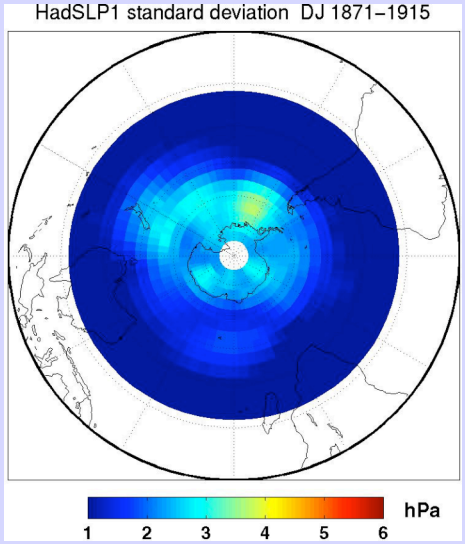
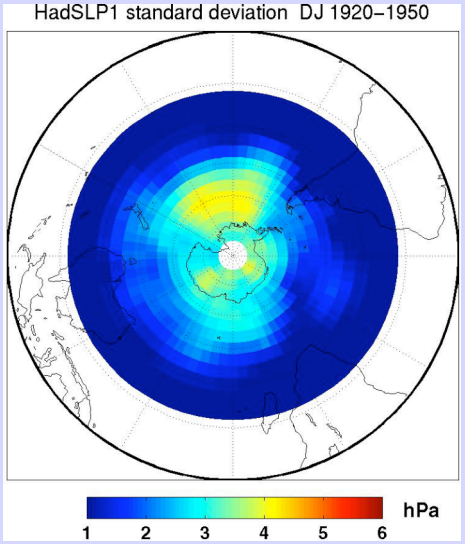
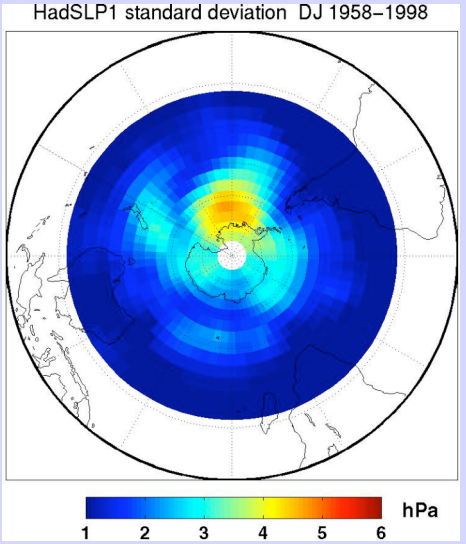
- 1866 until 1920-1950 window, agreement best between HadSLP1 and SBR than HadSLP2

DJ Mean SLP

	1871-1915	1920-1950	1958-1998
HadSLP2			
HadSLP1			

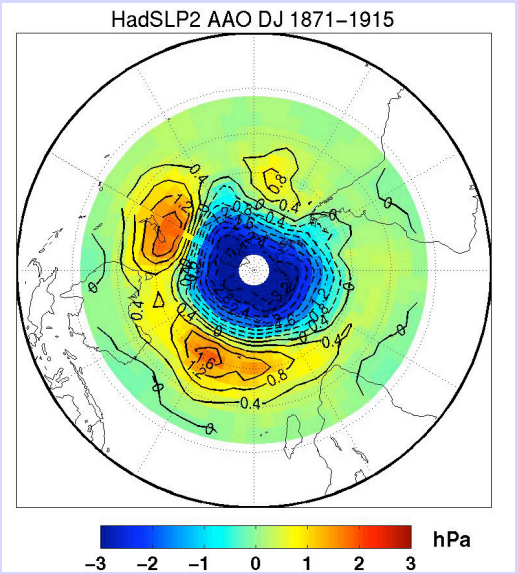
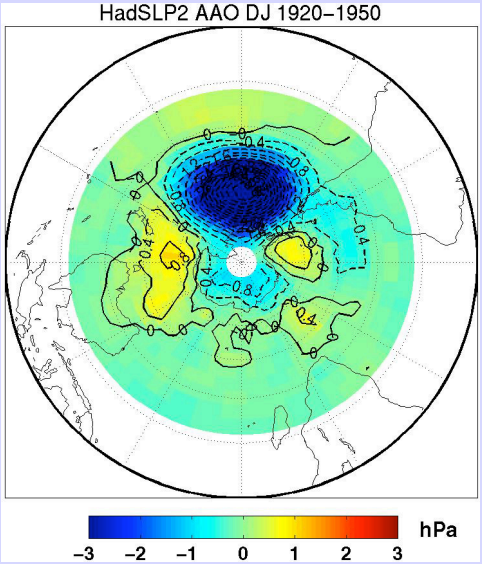
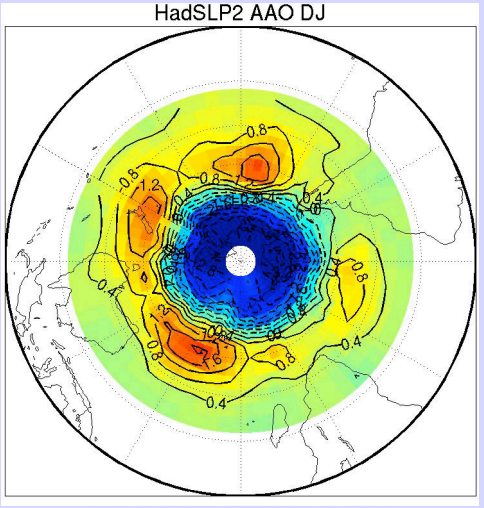
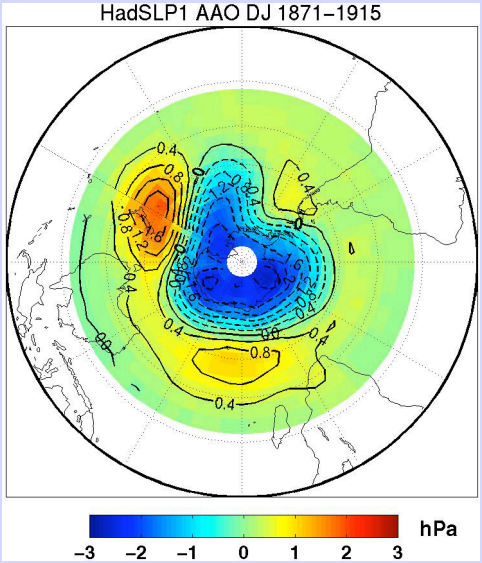
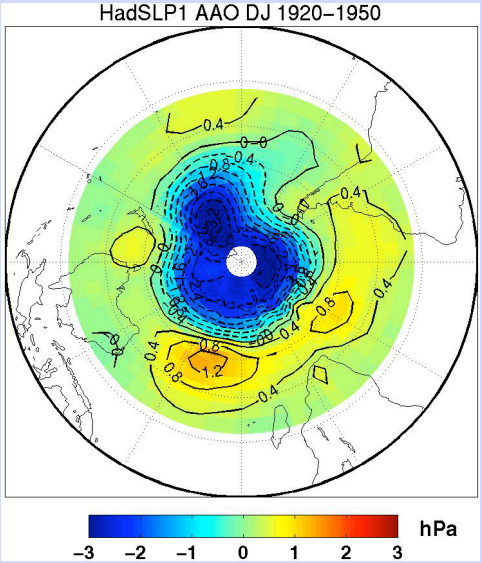
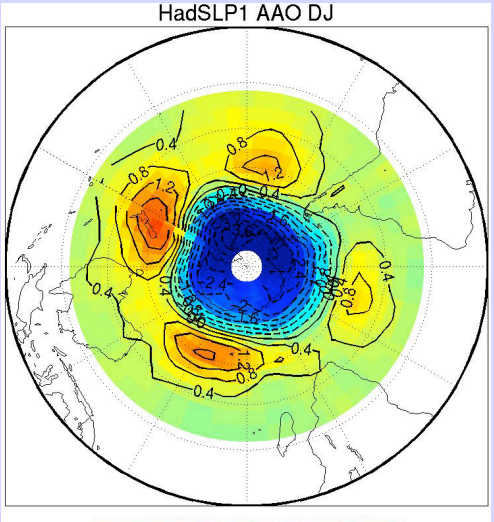
- small difference in the mean

DJ Standard Deviation

	1871-1915	1920-1950	1958-1998
HadSLP2			
HadSLP1			

- high standard deviation in the SE Pacific in HadSLP2 during the 1920-1950 period

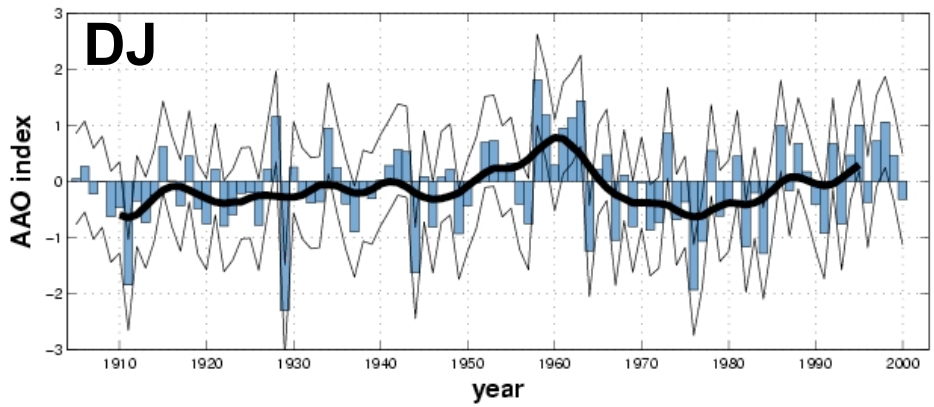
DJ SLP EOFs

	1871-1915	1920-1950	1958-1998
HadSLP2			
HadSLP1			

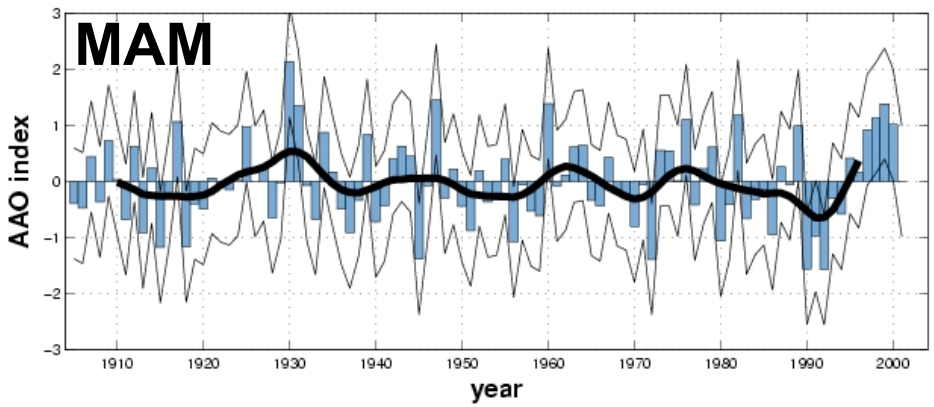
- differing EOF structure in the different periods, HadSLP2 1920-1950 has very high negative loadings in South Pacific

Can AAOI reconstructions and comparison with HadSLP AAOIs be undertaken in the other seasons?

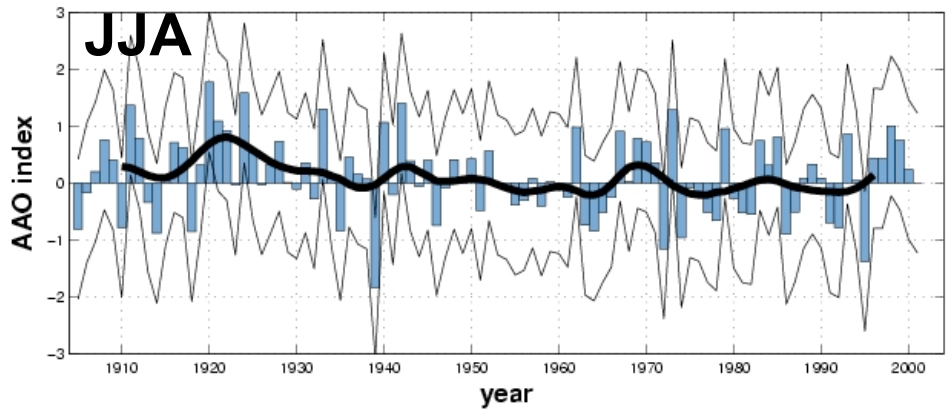
Reconstructions in other seasons have greater uncertainty



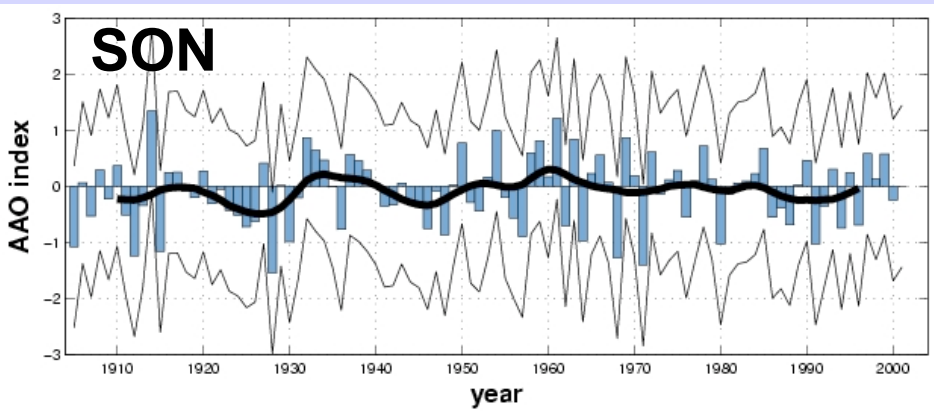
r_{val}=0.88 RE = 0.81, 22 stations



r_{val}= 0.75 RE= 0.58, 18 stations



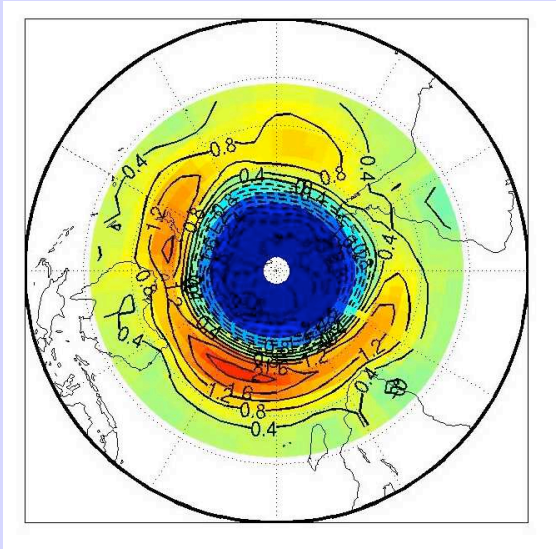
r_{val}=0.68 RE =0.45, 13 stations

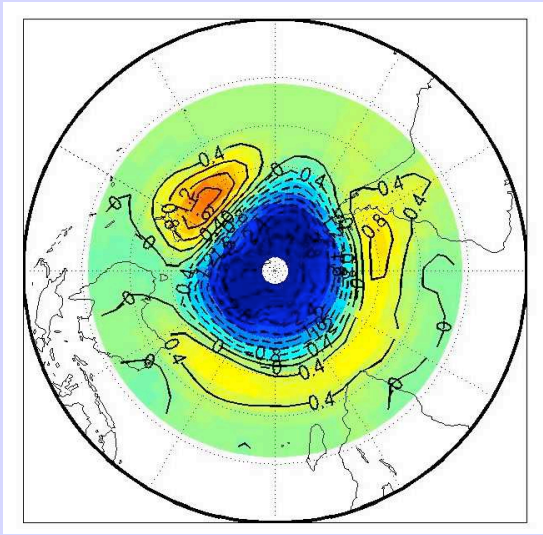


r_{val}=0.66 RE=0.44, 11 stations

ERA40 SLP EOFs

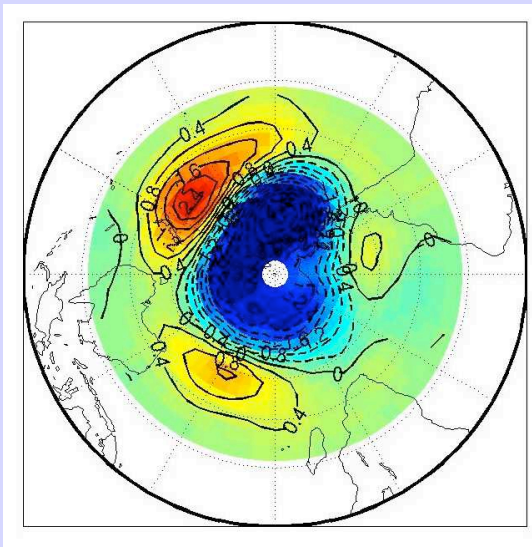
DJ
45%

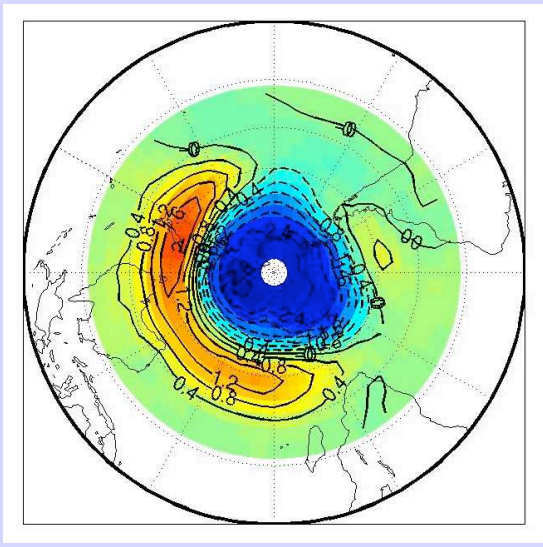




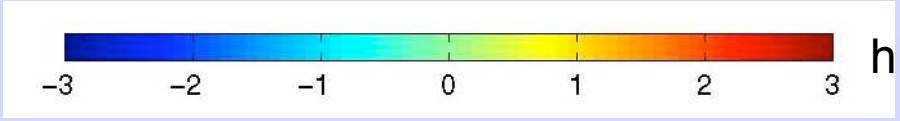
MAM
33%

JJA
31%



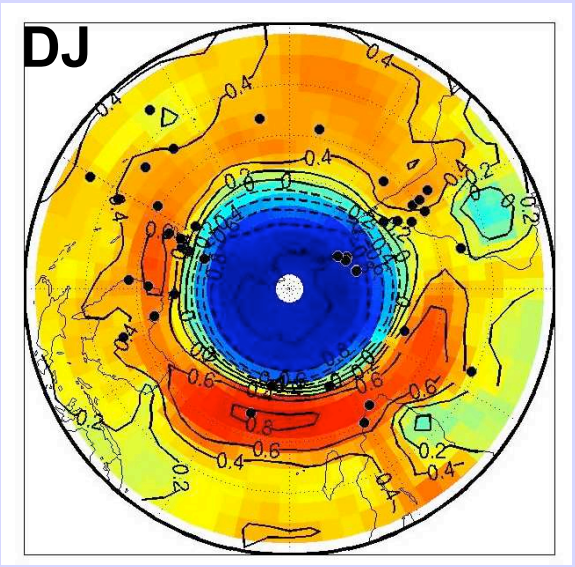


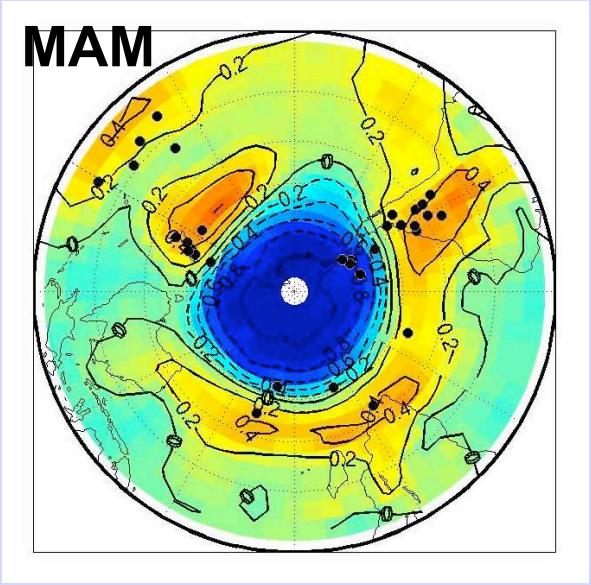
SON
28%

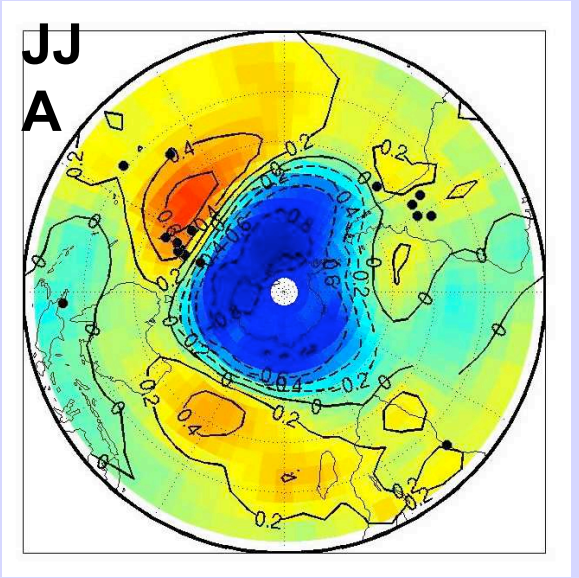


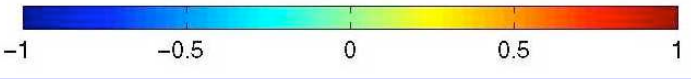
- the AAOI explains lower % variance of SLP in other seasons

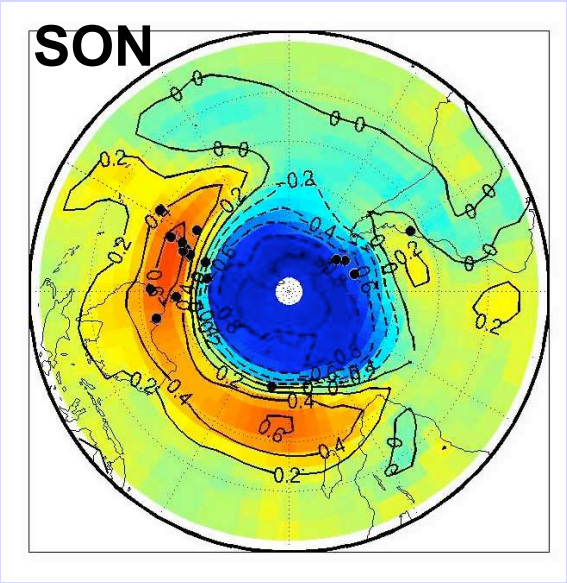
Correlation between detrended ERA40 AAOI and ERA40 SLP









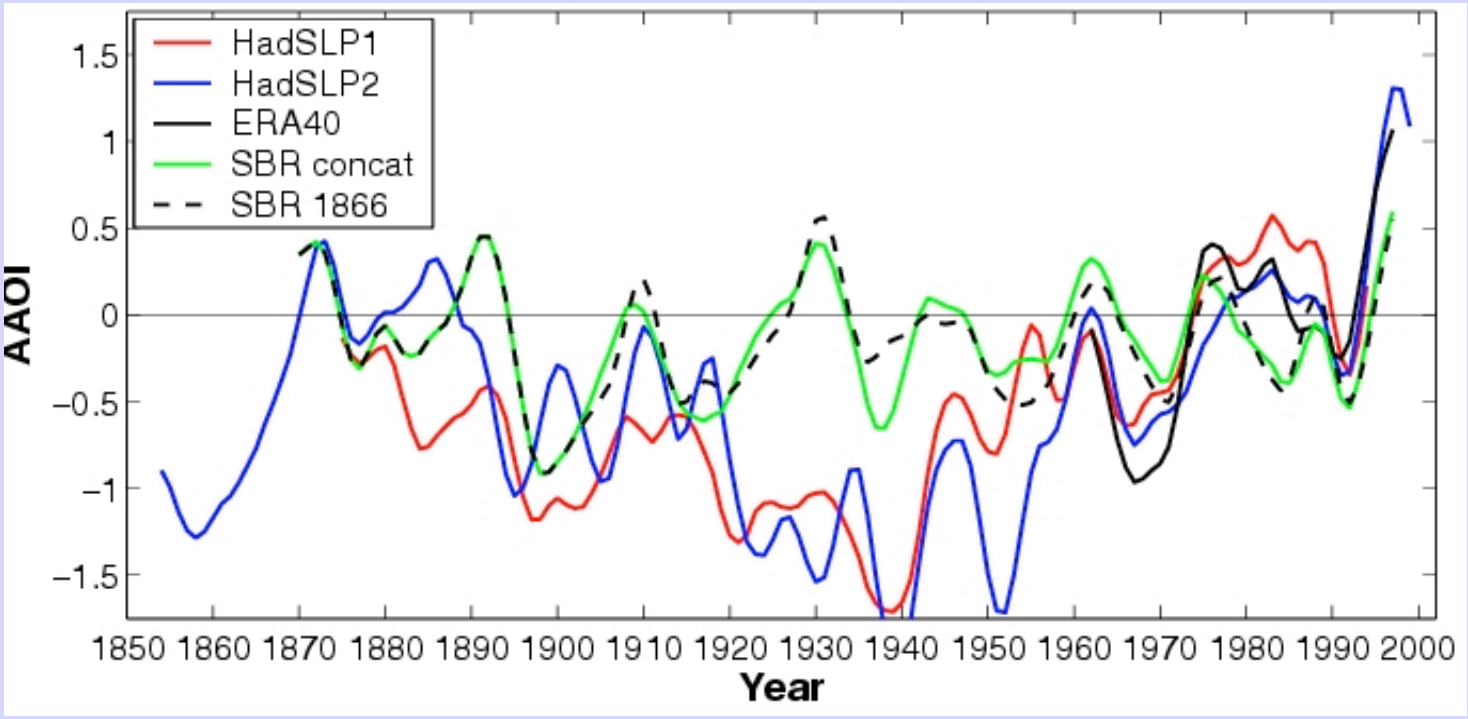


- local SLP variance explained by the AAOI over land areas lower in other seasons
- Also greater uncertainties in early ERA40 in JJA (Bromwich and Fogt 2004)

-> fewer stations highly/significantly correlated with the AAOI to input to reconstruction

MAM reconstruction back to 1866 possible

11 stations, r_{val}=0.74, RE = 0.54



- lower agreement than in DJ, probably because of greater uncertainty in the reconstruction
- as in DJ, poor agreement HadSLP1/2 and SBR 1920-1950
- high correlation of HadSLP1/2 with ERA40 AAOI (r=0.87/0.91)

Data Assimilation Through Upscaling and Nudging (DATUN)

Assimilation method for paleo simulations

- Include in model simulations aspects of random internal or not captured forced variability as estimated from proxies/instrumental data

- Assimilation of **large-scale** temperature or circulation anomalies from upscaling (e.g. AO, AAO) - pattern nudging

- Pattern nudging: push simulated amplitude of given pattern towards prescribed values without directly affecting orthogonal/other patterns or suppressing variability

- Simulation of the reaction on small scales, synoptic-scale variability, and non-nudged variables,

Pattern nudging can also be a tool for dynamical experiments

(Widmann, von Storch, Schnur, and Kirchner, in preparation)

Concept of Pattern Nudging

field expansion

$$\Psi(x,t) = \overline{\Psi}(x) + \alpha_T(t)\Phi_T(x) + \sum_{i=2}^{\infty} \alpha_i(t)\Phi_i(x)$$

$$\alpha_{mod}(t) = \frac{(\Delta\Psi(x,t), \Phi_T(x))}{(\Phi_T(x), \Phi_T(x))}$$

$$\Delta\Psi(x,t) = \Psi_{mod}(x,t) - \overline{\Psi}(x)$$

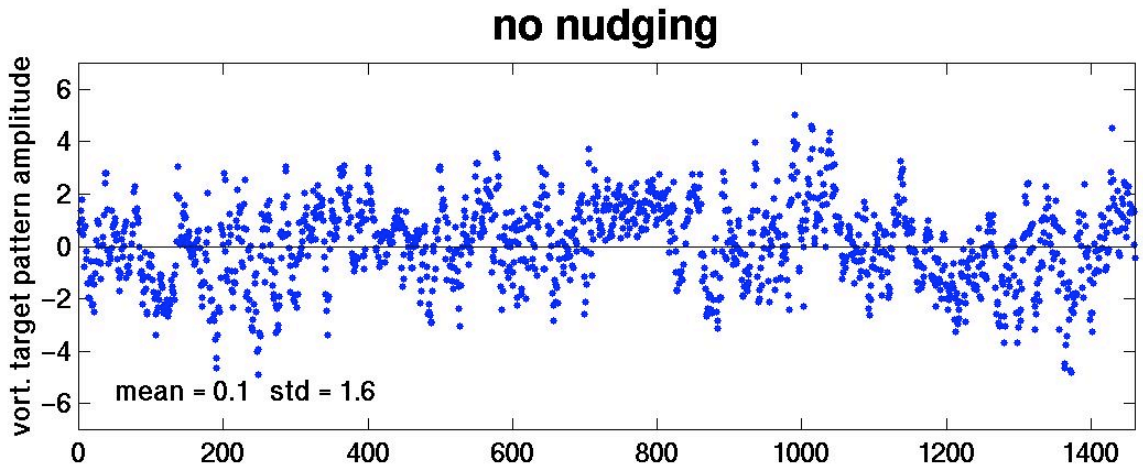
additional nudging term

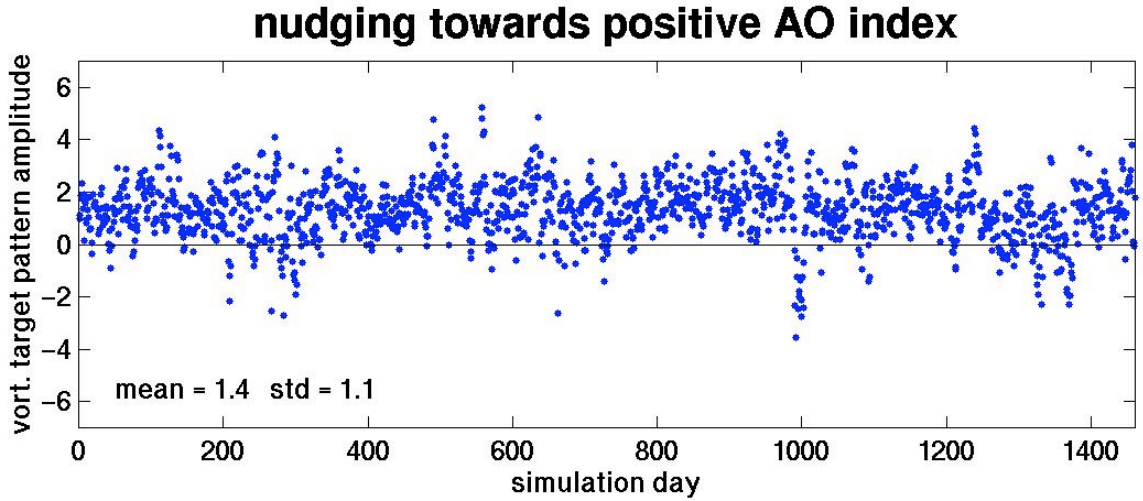
$$R = G\ (\alpha_T - \alpha_{mod}(t))\ \Phi_T(x)$$

Amplitudes of vorticity target pattern

(anomalies of simulated field projected onto target pattern)

target TEC = 2, t_relax = 2d

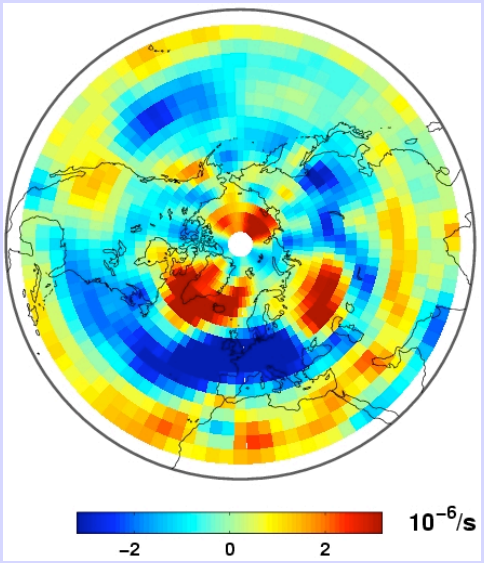


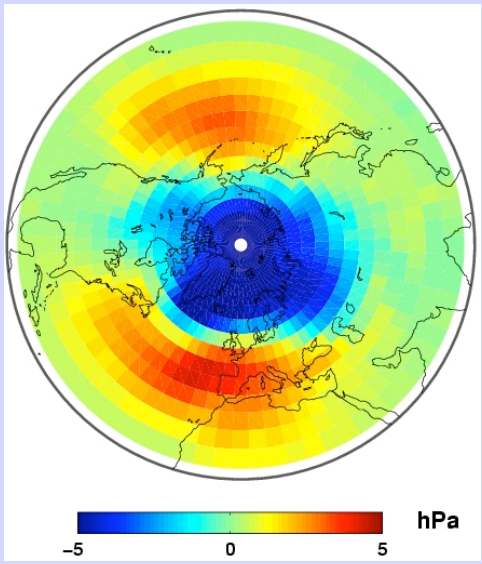


Nudging of the Arctic Oscillation in ECHAM 4

target field vorticity, January (11y), mean TEC = 1

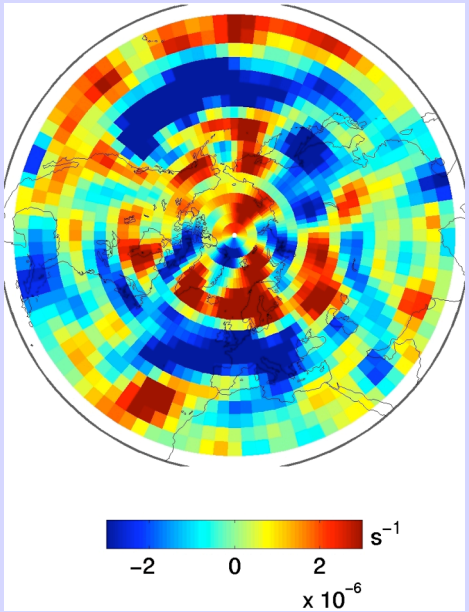
vorticity
target pattern
(L14, 850 hPa)

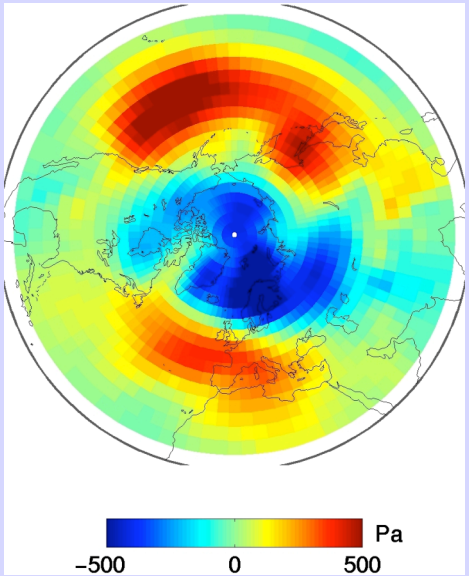




AO pattern
SLP EOF 1

ECHAM 4
vorticity
Nudging - CTRL
(L14, 850 hPa)



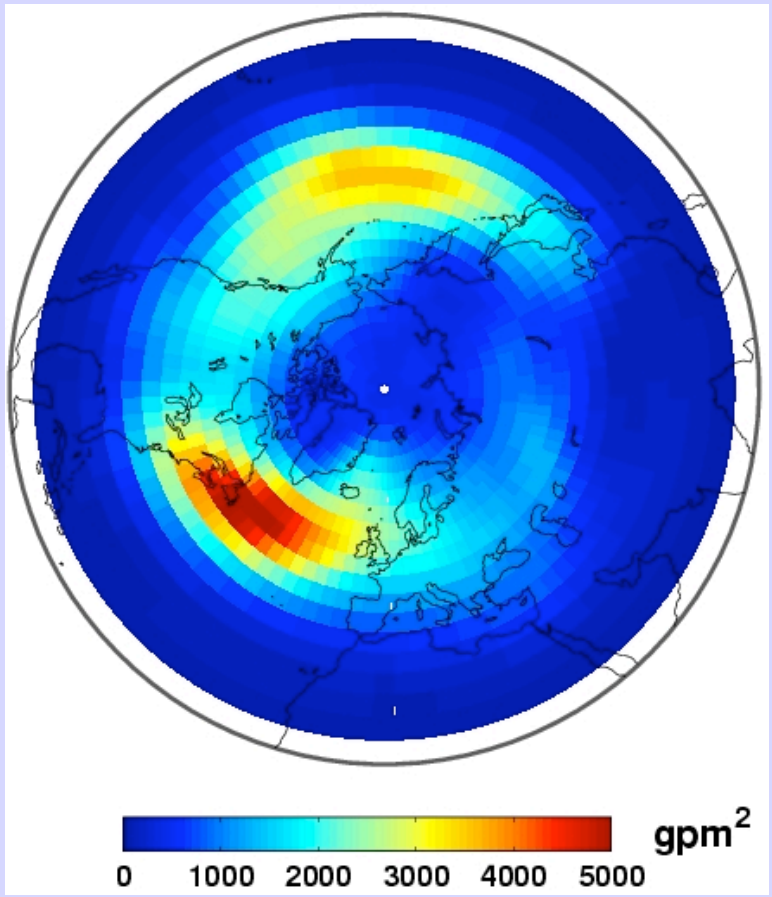


ECHAM 4
SLP
Nudging - CTRL

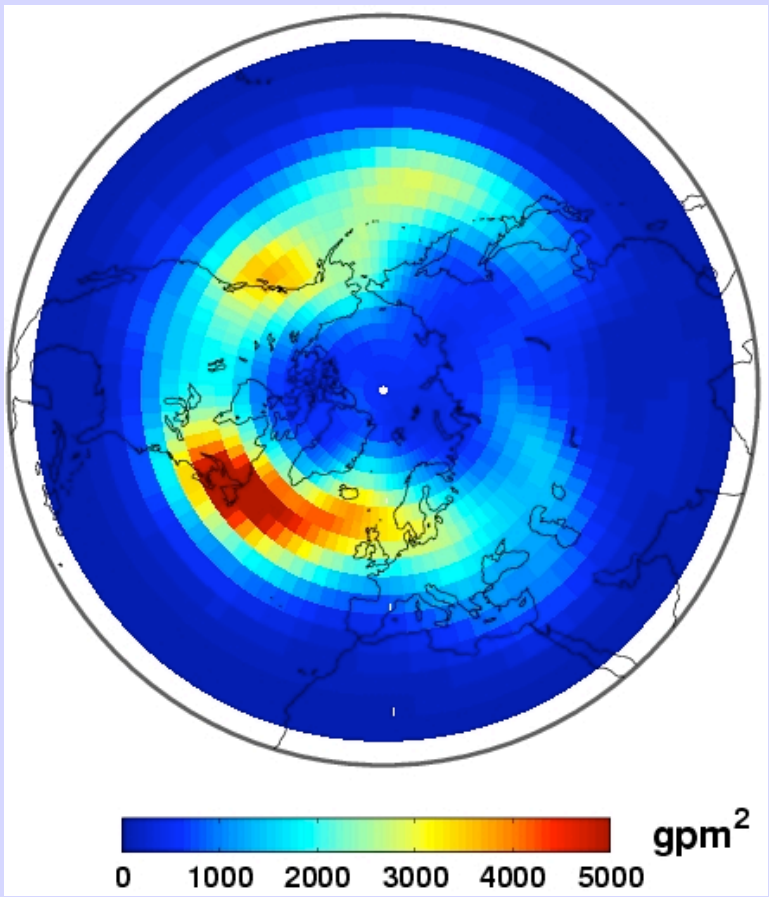
Stormtracks (DJF) with and without nudging

7y, t_relax = 12 h, mean TEC = 1.8
variance of 2.5d-6d bandpass filtered Z500

no nudging



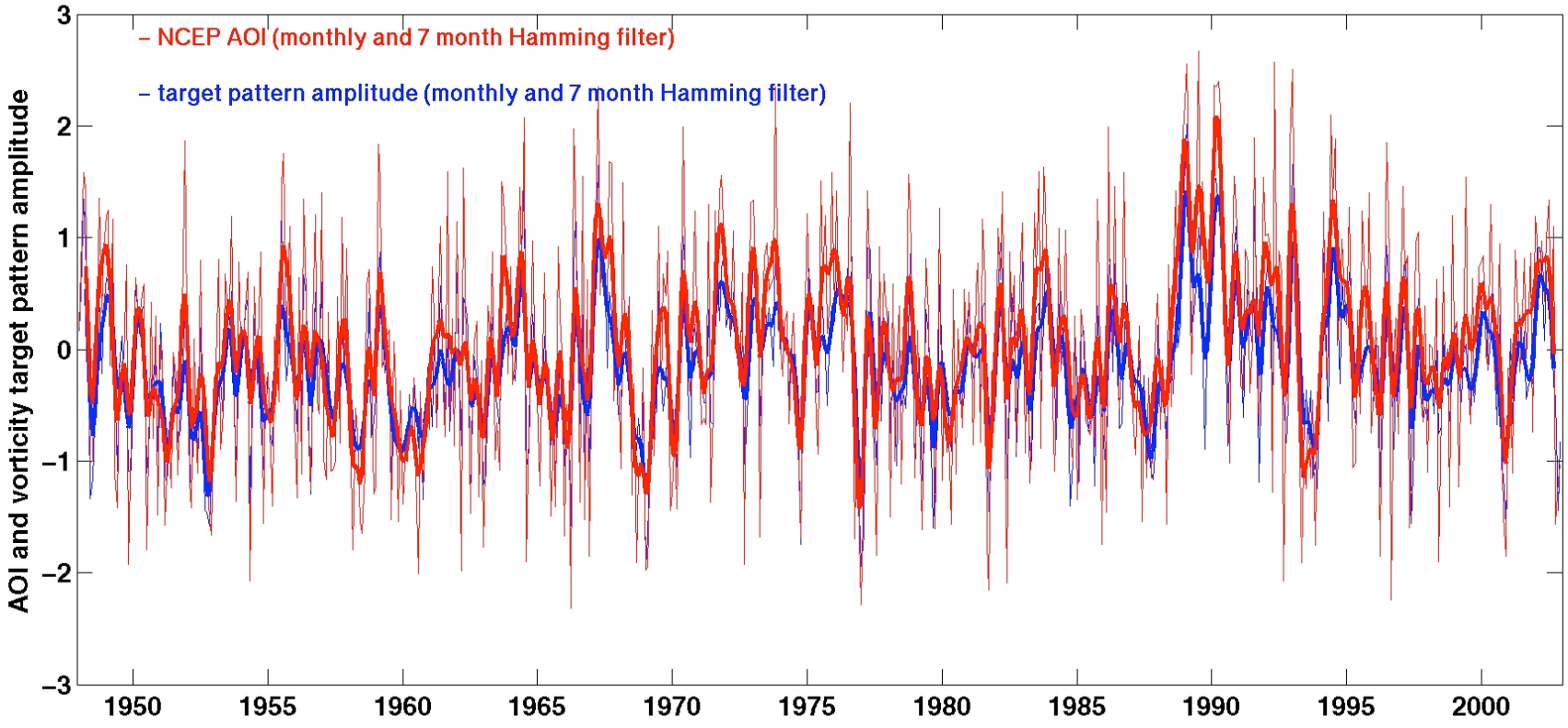
with nudging



(Widmann, von Storch, Schnur, and Kirchner, in preparation)

Pattern nudging towards the monthly NCEP AO Index

t_relax = 24 h



NCEP AOI

target pattern amplitude

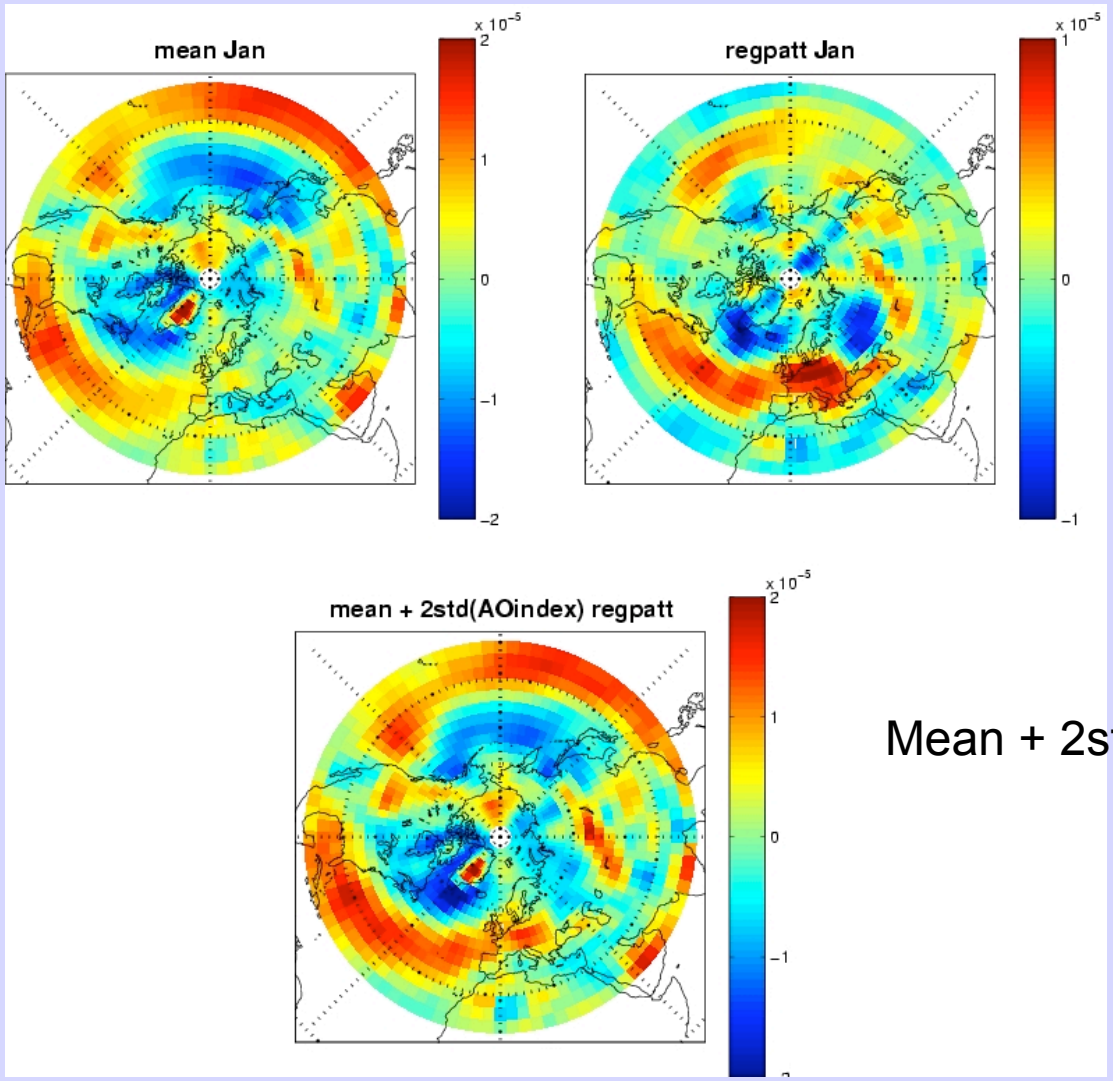
Conclusions

- Recent trends and current high positive values of the DJ AAOI appear not to be unprecedented, thus natural variability, either forced or unforced, must be capable of producing changes of a similar magnitude - can models capture this?
- Comparison of the DJ reconstructed AAOI (SBR) shows good agreement with HadSLP1/2, except for the 1920-1950 period
- Reconstructions more difficult in other seasons (particularly JJA, SON) because of:
  - location of AAO centres of action in relation to landmasses
  - lower % of SLP variance explained by the AAOI
  - more uncertainty in early reanalysis data
- MAM SBR also shows strong disagreement with HadSLP1/HadSLP2 during 1920-1950
- Test experiments of pattern nudging encouraging

Pattern Nudging: what we don‘t want

850 hPa relative vorticity: mean and signal of Arctic Oscillation (AO)

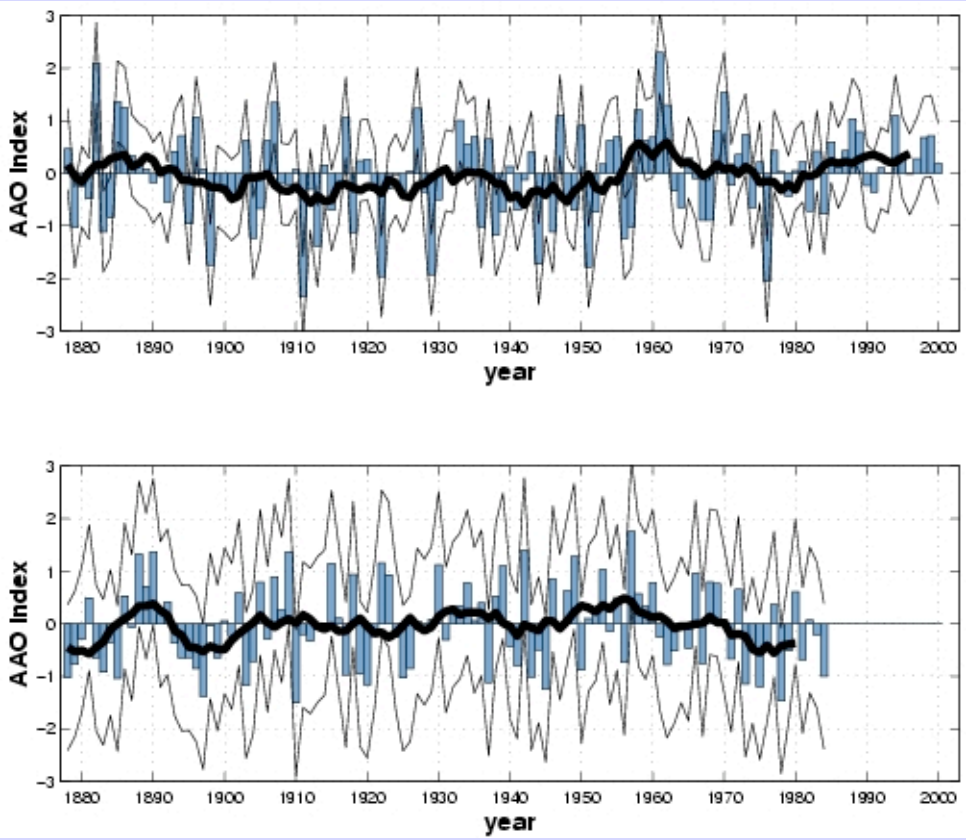
Mean 850hPa relative vorticity



NCEP 850 hPa relative vorticity regressed on extratrop. SLP PC1 (AOI)

Mean + 2std AO

Comparison of the station-based and tree-ring-based AAOI reconstructions



The station-based reconstruction (SBR) (undetrended data)

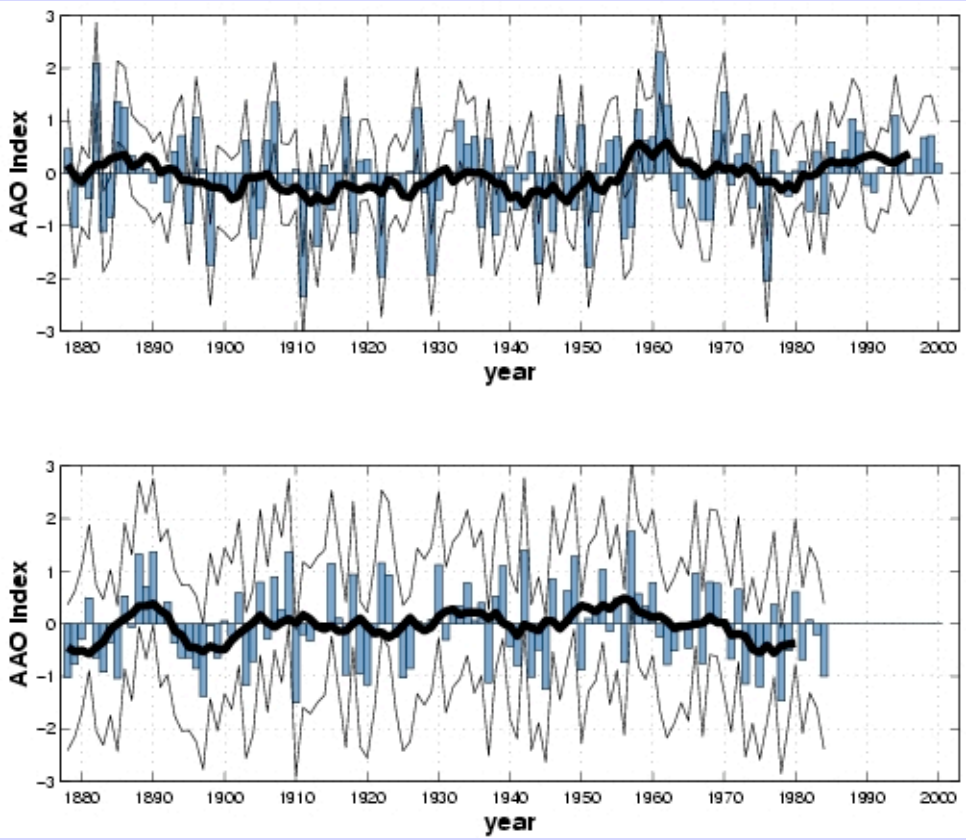
The tree-based reconstruction (TBR)

	1948-1985	1878-1985
r interannual	0.56	0.43
r 9-year running mean	0.26	0.38

- TBR more positive than SBR in first half of 20th century
- 1960s values higher than present in SBR, also high in TBR

END

Comparison of the station-based and tree-ring-based AAOI reconstructions



The station-based reconstruction (SBR) (undetrended data)

$r_{fit} = 0.92$
$r_{val} = 0.91$

The tree-based reconstruction (TBR)

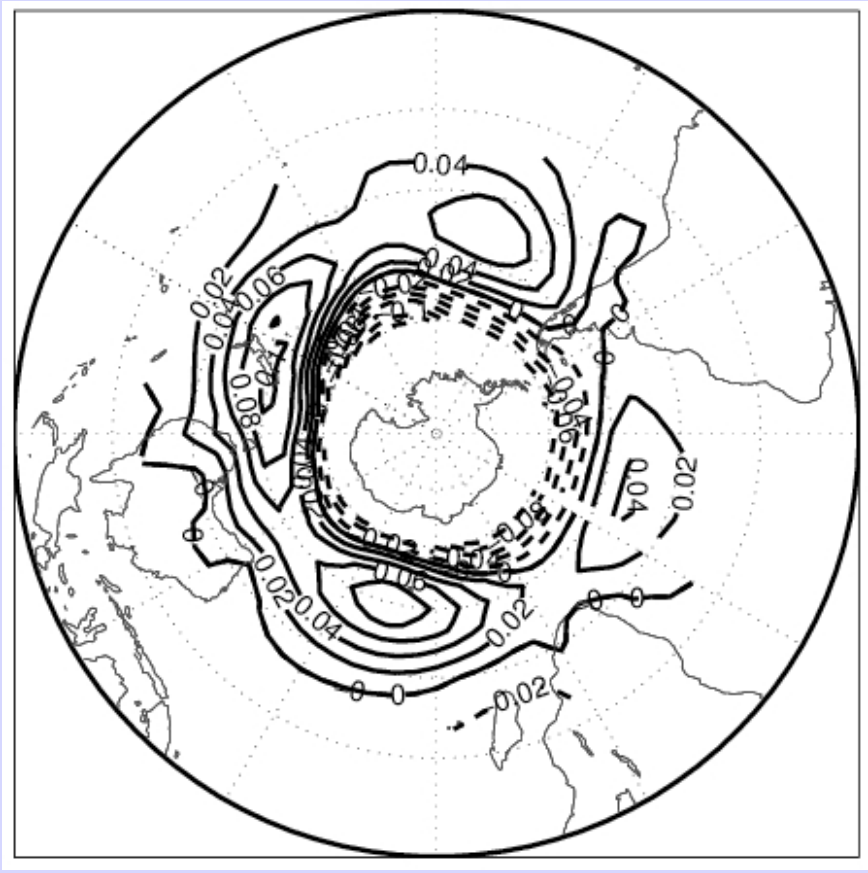
$r_{fit} = 0.72$
$r_{val} = 0.66$

	1948-1985	1878-1985
r interannual	**0.56**	**0.43**
r 9-year running mean	**0.26**	**0.38**

- TBR more positive than SBR in first half of 20th century
- 1960s values higher than present in SBR, also high in TBR

Statistical climate reconstructions
- Antarctic Oscillation

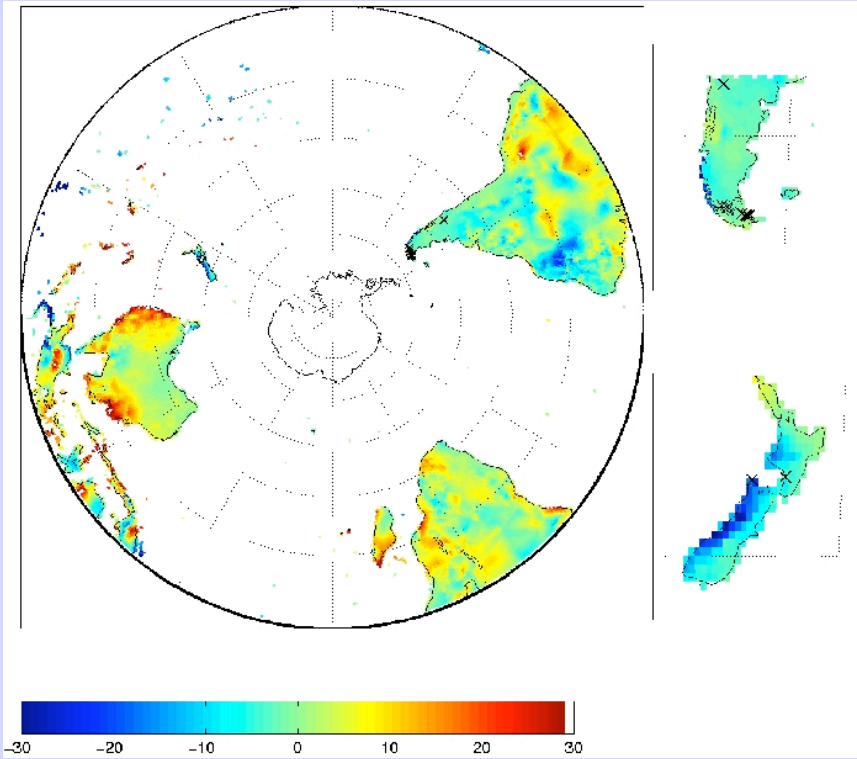
We define the AAO as EOF1 of detrended NCEP SLP for the domain 20ºS - 60ºS (NDJ)



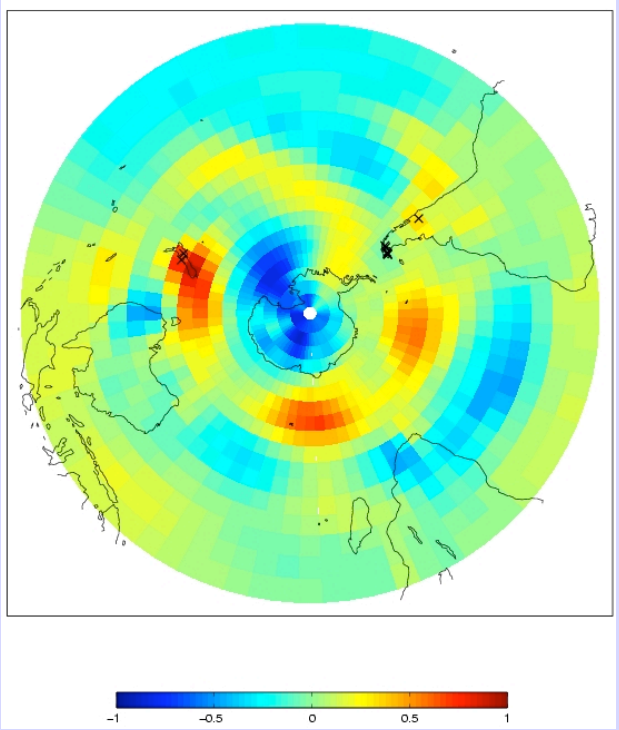
Strength of zonal flow around the Antarctic - positive index, stronger flow

The local climate signal of the AAO (NDJ)

Regression maps scaled to show mm precip or ^{o}C change for a 1σ change in the AAOI.

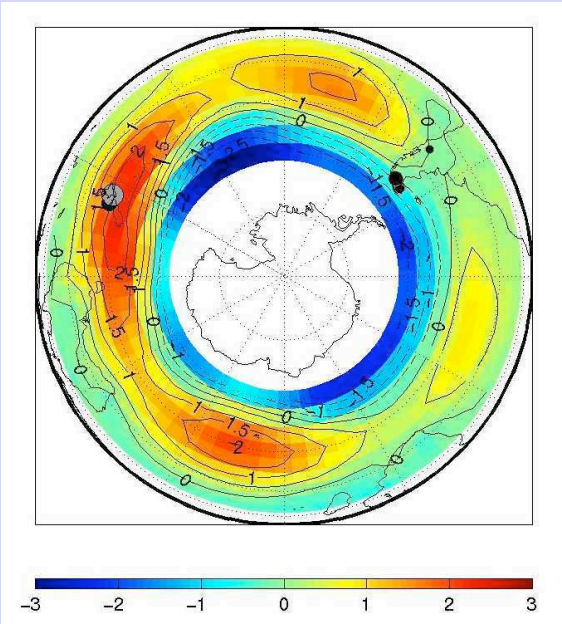


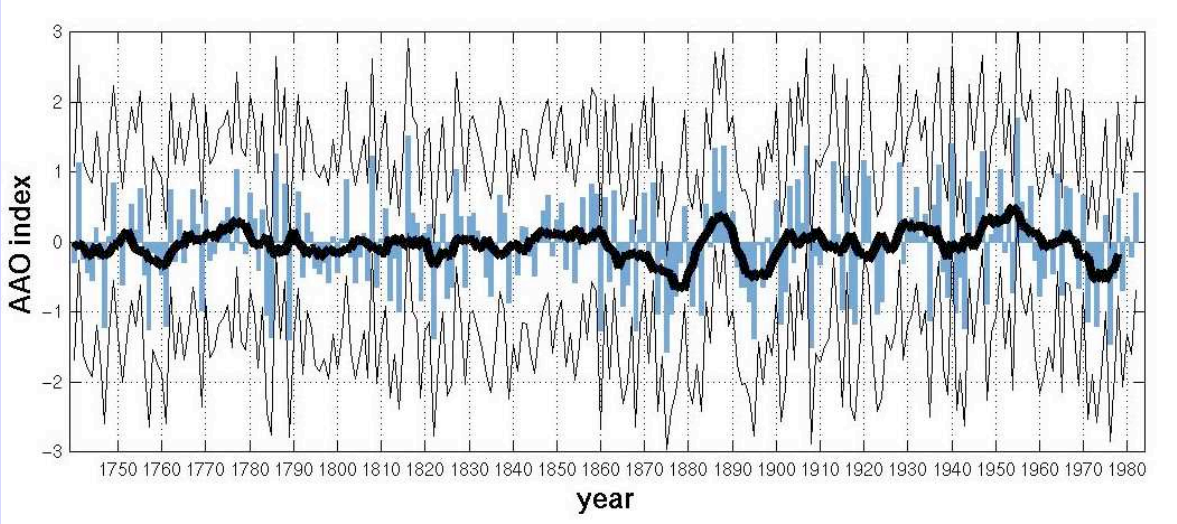
precipitation (New et al) and NCEP AAOI



temperature (NCEP 850hPa) and NCEP AAOI

Upscaling of 9 tree-ring width chronologies to produce NDJ AAOI reconstruction





9-year running mean

95% confidence intervals

r_{fit} = **0.72**

r_{val} = **0.66**

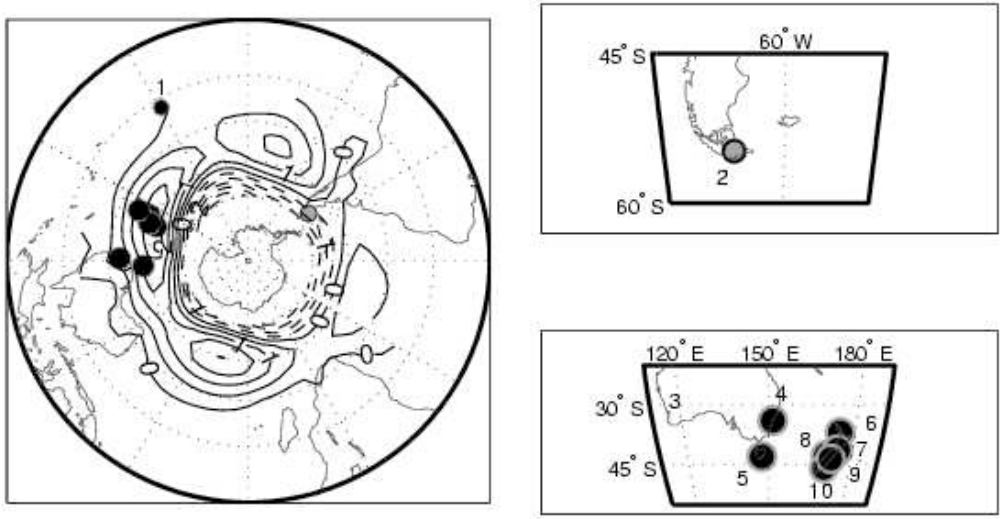
RE = **0.66**

Jones and Widmann, 2003: Instrument- and tree-ring-based estimates of the Antarctic Oscillation. *J. Climate*, **16**, 3511-3524

How reliable is this reconstruction outside of the fitting period?

We can test this by producing a reconstruction using station SLP measurements as the predictors.

28 stations (from a dataset kindly provided by Phil Jones) were chosen with data back to at least 1878, and PCR carried out as for the tree-ring data.



1 = Tahiti (–45.9, –149.6)
2 = Ushuaia (–54.8, –68.0)
3 = Perth (–31.9, 116.0)
4 = Sydney (–33.9, 151.2)
5 = Hobart (–42.9, 147.3)
6 = Auckland (–36.9, 174.8)
7 = Wellington (–41.3, 174.8)
8 = Hokitika (–42.7, 171.0)
9 = Christchurch (–43.5, 172.6)
10 = Dunedin (–45.9, 170.5)

Black- (grey-) filled circles = positive (negative) weight

r_{fit} = **0.92**
r_{val} = **0.91**
RE = **0.82**